Environmental Sound Perception of Cochlear Implant Users

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ABSTRACT

The purpose of this study was to develop a new test of environmental sound perception, The Environmental Sounds Perception Test (EST), and to both compare the performance of experienced cochlear implant (CI) recipients to age-equivalent normally hearing (NH) listeners using this new test, as well as pilot test its clinical use as a pre-to-post assessment tool. The closed-set EST consisted of 45 different sounds classified into 9 categories, with each sound being represented by two different tokens. The results showed that the NH participants scored significantly higher than the experienced CI users ($p < 0.001$). For the Pre-to-post CI group, higher scores were obtained post-surgery with the CI; this difference was approaching significance ($p = 0.068$). Overall these results suggest that CI recipients are poorer than NH participants, but better than hearing aid users with similar level of hearing loss, on the EST.

INTRODUCTION

The area of speech perception with a cochlear implant (CI) is very well researched, and it is well accepted that many recipients attain significant open-set speech recognition (Dowell et al., 2004, Hamzavi et al., 2003, Kiefer et al., 2004). However, factors other than speech perception contribute to the benefit a patient can obtain from their CI, and the impact of implantation on their quality of life. Surveys of the attitudes of recipients indicate that the reception of environmental sounds (e.g. nature sounds or warning signals) is another major benefit obtained from a CI (Tyler and Kelsay, 1990, Zhao et al., 1997). For example, for many patients, one of the first things they report to notice after their processor is switched on are background sounds like running water and computers humming (Tyler and Lowder, 1992).

Zhao et al. (1997) administered a benefits/problems questionnaire for 26 patients with a CI at 9 months post-implantation. They found that environmental sound awareness was reported by respondents as the main benefit they obtained from a CI (77%), followed by general ease of conversation (62%). In a study by Tyler and Kelsay (1990) involving 53 high-performing CI users, participants were asked to list the advantages they perceived from their CI in order of importance. The main reported advantages of implantation were improved speech and environmental sound perception. These benefits subsequently improved recipients' quality of life. For example, they reported feeling safer and more at ease in their environment, probably as a result of increased environmental predictability due to the ability to better perceive sounds around them (Tyler & Kelsay, 1990).

Reed and Delhorne (2005) measured the closed-set environmental sound perception performance of 11 adult CI patients. They designed a test using environmental sounds excerpts classified into four groups – General Home, Kitchen, Office, and Outside. Each group had 10 sound types, with each sound type being presented three times. A different token was used for each of these three presentations. A 10-alternative, forced-choice procedure was used. The mean percentage-correct scores across participants ranged from 45% – 94% correct (mean= 79.2%) across the four groups of sounds.

The rationale for this study arose as a review of the CI clinical outcome literature showed little objective research assessing the ability of CI users to identify environmental sounds. As is discussed above, identification of environmental sounds is an important skill which impacts on quality of life. It appears to be a presumed skill, but one that has attracted little objective research. Existing environmental sound perception studies primarily involved either subjective responses via surveys (Mo et al., 2004, Tyler and Kelsay, 1990, Zhao et al., 1997), or environmental sounds tests involving CI users only (Reed and Delhorne, 2005, Tye-Murray et al., 1992, Tyler and Lowder, 1992). There is little research comparing the performance of CI users with that of other populations, such as normally hearing (NH) listeners. Further, there is no published research investigating the ability of newly-implanted recipients to identify environmental sounds, nor research comparing the same subject pre-to-post surgery on such tests. It is also worth noting that many studies comparing CI users to NH listeners (on any perceptual task, not just environmental sound perception), have involved subject groups that are significantly different in age - i.e. older CI users than NH listeners. This brings up the question as to whether differences in the results of NH and CI participants could be due to age-related differences.

The environmental sounds tests used in previous studies have a number of limitations. Most of the previous environmental sounds tests have been closed-set tests with small set sizes.

The largest published closed-set test was the Iowa Environmental Sounds Test with 18 sounds for the closed-set list. This provides a chance-performance score of 6%. The only open-set test developed so far was by Proops et al. (1999), incorporating only 20 sounds, and using subjective marking criteria of correct, partially correct, or incorrect. In the previous studies CI users were able to achieve close to 100% on the environmental sounds tests. This suggests that ceiling effects may have to be accounted for in interpreting the findings. Another potential advantage to the development of a new environmental sounds test as part of this project, is that it may be useful in the clinical setting for pre- and/or post- implantation assessments. In order for a test to be implementable both pre- and post- implantation, the test needs to be of mid-range difficulty in order to avoid both floor and ceiling effects which may potentially be observed pre- and post- implantation, respectively.

The primary aims of this study were: (i) to develop a new, more comprehensive test of environmental sounds perception; (ii) to compare the performance of experienced CI users to age-equivalent NH listeners on this test; and iii) to pilot test its clinical application as a pre-to-post surgery assessment tool for environmental sound perception. To achieve these aims, NH participants, experienced CI users and participants on the waiting list for an implant who used hearing aids (HAs) were assessed using the developed Environmental Sounds Test (EST). The latter group were also re-assessed 3 months after switch-on of their CI.

It was hypothesised that: (i) the NH participants would score higher than the experienced CI users on the EST; and ii) for the Pre-to-post CI group, scores on the EST would be higher post-surgery than pre-surgery.

METHODS

Ethical approval for this study was obtained from The University of Canterbury Human Research Ethics Committee and from the Upper South Health and Disability Ethics Committee, New Zealand. All procedures were undertaken in accordance with these approvals.

PARTICIPANTS

Three groups of participants were recruited for this study:

1) 10 adult CI users – Experienced CI group. Participants ranged in age from 29-77 y (M = 57.6 y; SD = 16.4). Their experience with the CI ranged from 10-58 months (M = 27.3 months, SD = 13.5). More detail about this group is provided in Table 1. Their unaided pure-tone thresholds are listed in Table 2.
2) 4 adult HA users who subsequently received a CI – Pre-to-post CI group. They ranged in age from 43-66 y (M = 54.8 y). More detail about this group is provided in Table 3.
3) 24 normally hearing adults - NH group. Participants ranged in age from 23-72 y (M = 47.0 y, SD = 16.6). There was no significant difference ($p > 0.05$; t-test) between the age of the NH and experienced CI groups.

Place Tables 1, 2 & 3 near here

All CI users in this study, including the Pre-to-post CI group after surgery, used Cochlear Ltd. ‘Nucleus’ devices – either the C124R or the C124RE implant, with either the Esprit 3G or the Freedom speech processor. All participants used the ACE speech processing strategy with a stimulation rate of either 900 Hz or 1200 Hz. The four participants in the Pre-to-post CI group used bilateral HAs pre-implant.

For the experienced CI group, the inclusion criteria were that they were over 18 years of age, had at least 10 months experience with their implant, had no major cognitive impairments, and spoke English as their first language. For the pre-to post CI group, the selection criteria were similar except that participants needed to be regular HA users, have met the implantation criteria, and were scheduled to be implanted during the time period of the study. NH participants were included if they were over 18 years of age, and if they had hearing thresholds less than or equal to 25 dBHL at the octave frequencies between 0.5 kHz and 4 kHz.

THE ENVIRONMENTAL SOUNDS TEST (EST)

A closed-set test of environmental sound perception was developed for this study. The initial version of the EST included 50 different sounds, with two tokens for each sound (Table 4). The sounds were selected to be representative of stimuli that may be encountered in every day life. Effort was made to select a variety of sounds, with some easier to identify, or more obvious than others. The test sounds were chosen with consideration given to the frequency that these sounds occur in every day life. Out of the 50 sounds selected, 28 appear on the list of environmental sounds reported in the ecological frequency survey conducted by (Ballas, 1993). Twelve of the sounds incorporated into the EST that were not included on Ballas' list consist of human sounds, speech, music, and general sound environments (e.g. a general office environment). These sounds were excluded from (Ballas, 1993) ecological study. The other 10 sounds included in this EST were less common, but they either had distinctive or unique acoustic characteristics (e.g. breaking glass), were considered important warning signals (e.g. a fire siren), or were animal sounds or sounds from nature (e.g. a dog barking, or thunder). The sounds chosen for this test were classified into the following groups for later analyses: traffic noise, nature sounds, arriving home, bathroom sounds, kitchen sounds, household appliance sounds, human sounds, office sounds, and other sounds, as set out in Table 4.

Place Table 4 near here

All stimuli were obtained from commercially-available sound databases. The stimuli for the test were then created using the computer software program ‘Adobe Audition’. Each sound type was represented by two separate tokens; that is, the pilot version of the test comprised 100 separate sound files. The two different tokens were derived either from separate recordings or files (e.g. two different birds singing), or by sampling different sections of a single waveform (e.g. two separate samples from a long extract of traffic noise). The length of each sound token ranged from 2.5 sec for breaking glass to 12.5 sec for the fire siren. The length of the tokens were different for the different sound types in order to ensure that the extract was realistic and representative of the information available in the normal listening environment, without unnecessarily prolonging the test. For example, a single footstep may not provide adequate information for identification, with several footsteps in succession possibly required. However, the sound of a door closing is relatively brief, and prolonging its duration may result in an unrepresentative and unrealistic sound token. Continuous waveforms (e.g. continuous traffic noise or excerpts of different environments such as an office) had a 30 ms onset and offset ramp applied to minimise any distortion caused by a rapid on-set and/or off-set of the sound. For discrete waveforms (e.g. footsteps, door knocks, or glass breaking), tokens of the waveform commenced and ceased at natural silence breaks in the waveform. The speech stimuli incorporated into the EST allowed the assessment of the ability of participants to identify male and female voices, and to differentiate between a single speaker and many speakers. As the purpose of the stimuli was not for participants to identify the actual words and/or understand what the talker was saying, these speech extracts were spoken in a foreign language (i.e. German).

The EST was originally piloted on 5 normally hearing adults. A total of 49 errors were made in this pilot trial. Analysis of the confusion matrix showed that by removing five sounds from the test, 32 of the 49 confusions would be eliminated. Hence, the final version of the EST consisted of 45 sounds with 2 tokens each – i.e. 90 sound files. The eliminated stimuli are indicated in Table 4. This provided a chance performance rate of 2.2%. For calibration purposes a calibration tone (white noise) was generated at the average RMS level across the remaining 90 sound files.

PROCEDURES

All of the testing was undertaken in a quiet, sound-treated room. Ambient noise levels in the room prior to testing were less than 32 dB(A) as per the ANSI standards.

Participants for the two experimental groups (Pre-to-post surgery group, and the Experienced CI group) were asked to attend two test sessions, with the testing time for the initial appointment for both experimental groups being about 1.5 hours. For the Experienced CI group, puretone audiometry and speech perception data were collected by another researcher on the same day. Testing with the other researcher took about 1 hour with the EST taking approximately a further 30 minutes. The pre-surgery session for the Pre-to-post CI group was conducted in the month prior to implantation and involved obtaining bilateral hearing thresholds, speech perception data, and administering the EST.

The second session for both experimental groups was approximately 3-4 months following their first appointment. For the Pre-to-post CI group this meant that the follow-up session was approximately 3 months after switch-on of the CI. Accordingly, the Experienced CI group were asked to return approximately 3-4 months later for their retest in order to assess for the potential of a learning effect biasing the within-group comparisons for the Pre-to-post surgery participant group. For the Experienced CI group, the second session involved readministering the EST, with the session lasting approximately 30 minutes. For the Pre-to-post surgery group, the second session lasted approximately 1 hour. Hearing thresholds were obtained for the implanted ear, and both speech perception tests and the EST were re-administered.

For the pre-surgery session for the Pre-to-post surgery group, participants were assessed whilst using their own HAs. For the Experienced CI group, along with the post-surgery session for the Pre-to-post surgery group, participants were assessed whilst using their CI in the monaural implant-only listening condition. The decision to test in a CI-only condition (i.e. no HA on the other ear) was due to the fact that protocol for the clinic involved in this study was to recommend that patients use only their CI in the first 3 months post-implantation in order to allow their brain to adjust to the new sound. For all testing, participants were asked to use the settings they usually use for every day listening. Participants were able to adjust the settings of their CI or HA (i.e. volume and/or sensitivity controls) to their preferred level prior to testing commencing.

The NH group attended one test session. Their hearing was firstly screened to confirm that they had hearing thresholds at the octave frequencies between 0.5 and 4 kHz ≤ 25 dB HL. They then undertook the EST which took approximately 20 - 30 minutes.

For the speech tests and the EST, stimuli were presented via a loudspeaker placed at 0 degrees azimuth, 1 metre from the listener's ear. Presentation levels were calibrated to be 65 dB(A) at the position of the participant's ear, using a sound level meter. The stimuli for the EST were delivered via a computer, connected to an amplifier, a graphic equalizer, an audiomixer, and a sound field speaker. Test items were stored on the computer as .WAV files, and a computer program ('UC_ID')[1] presented the stimuli in random order. The program allowed the experimenter to have control over the timing of the presentations, and the responses were entered directly into the program for later analysis. The participant had a list of the environmental sounds, and they were asked to select the sound that they thought was played. Participants were given as long as necessary to make their decision, and no feedback was given regarding the accuracy of their answers during the test itself. Stimuli were not replayed. As the final version of the test had 45 different sounds with two tokens each, a score out of 90 was obtained which was then converted to a percentage-correct.

It should be noted that all of the experimental participants had been fitted with individually optimised HAs/ CI as part of their routine audiological care. Therefore the HA or CI settings used by the patient in these sessions should have been the most-appropriate settings for the patient to obtain the greatest listening benefit from their device.

RESULTS

For the EST results, confusion matrices were constructed to provide information on participants' responses and error patterns. For all of the confusion matrices that follow, the

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[1] The UC_ID program was developed by Dr G. O'Beirne, at the University of Canterbury. The software enables selected sound files on the computer to be presented to listeners, at a controlled presentation level. Although various set-up configurations are available, for this study, the files were presented in a random order, with the responses entered directly into the program. Upon conclusion of the test, an output file was generated containing details of the sound file presented, the corresponding response made by the subject, and a percentage-correct score.

stimulus is indicated by the column while the response is indicated by the row. The letters representing the stimuli correspond to the sound indicated with those same letters in the response column. The numbers within each cell represents the number of times a given response was provided for a given stimulus. The shaded squares indicate the number of sound tokens correctly identified, and the unshaded squares indicate confusions made. For example in Table 5, for the stimulus 'aeroplane', the correct response of 'aeroplane' was provided 37 times. Other responses (confusions) that were provided included 'helicopter', 'hairdryer' and 'construction site' three times each, and 'alarm' and 'train' a single time each. For the EST, each sound type had two different tokens that were presented during the test. Therefore the total number of responses for each stimulus was 2nt (where n = number of participants in the group and t = the number of times each participant was assessed). This number is provided for each column in the row entitled "total responses". For example in Table 5, the total number of responses for each stimulus is 2 x 24 participants x 1 assessment, i.e. a total of 48 responses. The bottom row of each confusion matrix indicates the percentage that each sound stimulus was correctly identified. The total in the bottom right corner of the matrix indicates the mean percentage-correct for the entire EST for the relevant group of participants. For example, Table 5 shows that the mean percentage-correct for the NH group on the entire EST was 92.92%.

Normally Hearing Participants

The confusion matrix for the NH group is presented in Table 5. The mean total percentage-correct score on the EST was 92.92% (SD = 4.28), with 70% of the errors accounted for by the 12 most-common confusions. A one-way repeated-measures Analysis of Variance (ANOVA) showed a significant difference between the categories ($p = 0.013$). Post-hoc analysis using Bonferroni corrections showed the significant differences to be between the most-accurately recognised category (human), and the two least-accurately recognised categories of household (p = 0.007) and office (p = 0.020). There was no significant correlation between overall participants' score on the EST and their age (p = 0.703; Spearman's rho).

Place Table 5 near here

Experienced CI Users

The experienced CI group was assessed twice. The Pearson's correlation coefficient (r = 0.891) suggested strong test-retest reliability for this test. The mean score and standard deviation (SD) for each category for the initial and follow-up tests are shown in Table 6 below. A 2-way repeated-measures ANOVA showed no significant difference between the initial and follow-up administrations of the EST and therefore the following analyses use the combined results for both test blocks of the EST. The confusion matrix (combined data of both test administrations) for the Experienced CI group is shown in Table 7. The mean total percentage-correct score on the EST was 59.28% (SD = 11.48). The error pattern exhibited by this group was more diffuse than the NH group with the 28 most-common confusions only accounting for 31% of the errors.

Place Tables 6 & 7 near here

The 2-way repeated measures ANOVA referred to earlier also looked at differences between the sound categories in addition to the different test administrations. A significant difference between the categories was found (p = 0.004), with no significant interaction between the factors of test block and category (p = 0.454). Post-hoc analysis using Bonferroni corrections showed the significant difference for the factor of category to arise from the two most-accurately recognised categories (human, and arriving home) being significantly better than the least-accurately recognised category of transport (human & transport $p = 0.01$; arriving home & transport $p = 0.028$).

Spearman's rho analyses showed no significant correlation between the overall score on the EST and the participant factors of age, duration of hearing loss pre-implantation, duration of CI use, degree of residual hearing, or any of the speech perception tests in quiet or noise. For the degree of residual hearing, this was based on the LFA as reported in Table 1.

Comparison of NH Participants and Experienced CI Users

As discussed in the previous section, there was no significant difference between the initial and follow-up results for the experienced CI group. In view of this, the scores for each participant from the two runs were averaged and used for the analyses in this section.

In order to see if there was any significant difference between the performance of the NH and the experienced CI groups, a 2-way repeated measures ANOVA was conducted using the between-subject factor of group and the within-subject factor of category. This showed a significant difference between groups ($p < 0.001$) and between categories ($p < 0.001$), as well as a significant interaction between these two factors ($p < 0.001$). The differences between the categories for each group have been discussed above. Figure 1 shows the mean percentage-correct score for the NH listeners and the CI users for each sound category.

Place Figure 1 near here

Pre-to-post CI Participant Group

The mean total percentage-correct score on the EST pre-surgery was 39.72% (SD = 14.27). The mean total percentage-correct score on the EST post-surgery was 57.22% (SD = 21.42). A non-parametric Wilcoxon Signed Ranks Test was conducted to see if there was any difference between the pre-to-post surgery means for the EST. The difference was approaching significance ($p = 0.068$) with the post-surgery score (with the CI) being higher than the pre-surgery score (with HAs). For the four participants, the total number of errors was 217 pre-surgery, and 154 post-surgery. The pre-surgery confusion matrix for these surgery participants is shown in Table 8, with post-surgery matrix being shown in Table 9. A comparison of the pre- and post-surgery percentage-correct scores for each category is shown in Table 10 and Figure 2. For each category, recognition scores were higher post-surgery (with CIs) than pre-surgery (with HAs).

Place Tables 8, 9 & 10 near here

Place Figure 2 near here

Spearman's rho analyses showed no significant correlation pre- or post-surgery between the overall score on the EST and the participant factors of age, duration of hearing loss pre-surgery, or any of the speech tests in quiet or noise.

DISCUSSION

The main aim of this study was to develop a more comprehensive test of environmental sound perception (the EST), to compare the performance of experienced CI users to age-equivalent NH listeners on this test, and to pilot test its clinical application as a pre-to-post surgery assessment tool for environmental sound perception.

NH Group vs. Experienced CI group Comparisons

The results of the current study support the first hypothesis, with the NH group scoring significantly better than the Experienced CI group on the EST. As there was no significant difference in the ages of the two groups, age-related factors that may have contributed to the results of previous studies are less applicable to this study. A significant difference was also found between the sound categories on the EST along with a significant interaction. This indicates that not only were some sound categories better recognised than others, but also that the NH and Experienced CI groups differed in terms of the relative difficulty experienced with the different sound categories.

There was also a difference between the confusion patterns of the two groups with the Experienced CI group exhibiting substantially more diffuse error patterns than the NH group. All, except one, of the sounds confused by the NH group involved continuous waveforms with similar spectral characteristics. This suggests that temporal cues were well perceived by the NH group, with subtle differences in spectral characteristics being the most common cause of confusions. The only commonly-made confusion from the NH group that did not involve a continuous waveform was the identification of ‘knock on the door ‘as a ‘construction’ site. This may have been due to the door knock being perceived as ‘hammering a nail’, which would be applicable to a construction site. Common errors that both the NH and Experienced CI groups shared were identifying ‘wind’ as ‘train’, ‘office’ as ‘restaurant’, ‘tap running’ as ‘river/ stream babbling’, ‘food frying’ as ‘tap running’, and ‘thunder’ as ‘wind’. Again these were continuous waveforms with similar acoustic characteristics.

Of greater interest is how the two groups performed differently from each other. Most of the additional errors made by the Experienced CI group were also continuous waveforms with similar spectral characteristics. It seems quite likely that the spectral differentiation difficulty displayed by the NH group was exaggerated further for the Experienced CI group. This is not surprising since a CI cannot provide the same degree of spectral resolution as the normally hearing auditory system. Similar to the findings from the study by Reed and Delhorne (2005), stimuli with distinct temporal characteristics were more accurately recognised by CI users, with confused sounds usually having similar temporal characteristics. A few of the common-confusions made by the Experienced CI group were very different to those made by the NH group. These confusions can be separated into three groups: confusion of voice stimuli, confusion of high-frequency stimuli, and confusion of temporally similar stimuli. The most common confusion for the Experienced CI group was identifying the 'many males and females talking at the same time' stimuli as 'one male and one female talking at the same time'. As well as this, two of the other common-confusions were mistaking either the 'one male and female talking at the same time' or the 'many males and females talking at the same time' stimuli, for the 'single male voice' stimulus. Confusions between voice stimuli were common in the Experienced CI group, but not so for the NH group.

It was also common for Experienced CI users to make confusions between different high-frequency stimuli with similar temporal characteristics. Examples of this included identifying 'glass breaking' as 'keys jangling', and identifying 'keys jangling' as 'food frying'. This may be in part due to the crude spectral analysis performed by the speech processing strategy of the CI, and/or it could be related to CI users having been deprived of hearing high-frequency sounds for many years as a result of their hearing loss. For example, it is possible that although the CI enables them to better perceive the higher frequencies, they are still learning to interpret and differentiate between such sounds.

It was also common for Experienced CI users to confuse stimuli with similar temporal characteristics. The ‘dripping tap’ stimulus was identified as ‘footsteps’, and ‘footsteps’ was often identified as the ‘construction site’ stimulus (i.e. hammering nails). CI users tend to be more reliant on temporal cues than NH listeners; therefore the differences in the temporal characteristics of these sounds may not have been sufficient to enable accurate recognition.

For all CI users, (i.e. both the Pre-to-post surgery group after surgery, and the Experienced CI users) testing was carried out in the implant-only condition. However, the opposite ear was not occluded for testing and therefore it should be considered whether residual hearing in the non-implanted ear contributed to their performance. The absence of a significant correlation between the LFA (Table 1) and EST scores for the Experienced CI group suggests that the residual hearing in the unimplanted did not significantly contribute to performance on the EST.

The finding that EST scores did not significantly correlate with any of the speech perception measures is consistent with the findings of Reed and Delhorne's (2005) study. This suggests that environmental sound perception is a separate skill, and not simply an extension of speech perception. Accordingly, this highlights the value of incorporating environmental sound perception testing when assessing CI benefit. In this study, EST scores did not correlate with the participant factors of age, duration of hearing loss, duration of CI use, or degree of residual hearing, suggesting that these were not confounding variables in this study.

Pre-to-Post Surgery Comparisons

This study also looked at the effect of cochlear implantation on environmental sound perception, by assessing patients on the waiting list for CI surgery prior to surgery whilst they were wearing HAs, and then following up these same participants 3 months post switch-on of their CI. Their mean percentage-correct score on the EST increased by 17.5 percentage points pre-to-post surgery. This difference approached significance ($p = 0.068$), and had there been more participants, a statistically significant difference may have be obtained.

As was found for the Experienced CI users, most of the confusions for this pre-to-post surgery group both before and after surgery involved continuous waveforms with similar spectral characteristics. The pre-surgery confusion matrix showed common confusions to include the misidentification of ‘doing dishes’ as ‘office’, ‘clock ticking’ as ‘knock on the door’, ‘cat(s) meowing’ as ‘birds chirping’, and ‘alarm clock’ as ‘whistling kettle’. These confusions are potentially related to the importance of higher frequency spectral cues for their differentiation. These participants, pre-surgery whilst wearing their HA(s), would have had very limited access to high frequency acoustic information due to their hearing loss.

As would be expected, post-surgery, confusions were most similar to that of the Experienced CI group. As with the Experienced CI group, most of these confusions could be separated into three groups: confusion of voice stimuli, confusion of high-frequency stimuli, and confusion of temporally similar stimuli. The most common voice stimuli confusion made by this group post-surgery was identifying ‘one male and female talking at the same time’ as ‘many males and females talking at the same time’. Other common confusions for these newly-implanted CI users, were identifying ‘aeroplane’ as ‘traffic’, ‘glass breaking’ as ‘keys jangling’, ‘tap dripping’ as ‘footsteps’. These sounds are temporally similar, and differ primarily in their spectral characteristics. Two other common confusions made by the newly implanted CI users were the identification of ‘keys jangling’ as a ‘running tap’, and ‘tap dripping’ as a ‘clock ticking’ - sounds which were similar both temporally and spectrally.

As mentioned earlier, factors related to the reduced spectral resolution and/or deprivation for high frequency sounds may in-part account for the difficulty with differentiating sounds based on their spectral characteristics. The error patterns again highlight the importance of temporal information for the significantly hearing impaired for recognising environmental sounds.

Learning Effect

The finding that there was no significant change in performance on the EST between test sessions for the Experienced CI group indicates the absence of a task-related ‘learning effect’ or test-retest variation. This is a relevant consideration in this study as the absence of a learning effect or retest variation suggests that the difference in the performance on the EST for the Pre-to-post surgery group may be largely attributable to the different devices (i.e. HAs vs. CI). However, it may also be possible that other non-device factors contributed to the better post-surgery scores observed. For example, concentration or attention could have been a factor, and the possibility of a ‘halo effect’ must be considered – i.e. the expectation that the new device (the CI) would perform better than the old device (the HA). A lot of time, pain, stress, and money is involved in cochlear implantation. Patients considering a CI are usually very keen for an improvement in their ability to hear, and often make significant emotional, physical, social, and financial sacrifices. Although ensuring that patients have realistic expectations for the CI is part of the assessment and counselling process, it would not be unreasonable for the patient to expect some degree of benefit from the CI. These factors could result in an increased level of concentration or effort displayed by the patient in the post-surgery test session, compared to pre-surgery. This could be further confounded by the attitude pre-surgery that “I get nothing from my HAs”, or that “the HAs are not doing anything so why bother trying?”

The EST

The main aim in the development of the EST for this study was to have a more difficult and more comprehensive test than those used in previous research to avoid the possibility of ceiling effects impacting on the results obtained. This study had the largest closed-set size of all ESTs for CI users published in the literature thus far, with a chance-performance rate of 2.2%. The results of the current EST suggest reduced potential of ceiling or floor effects. The best NH listeners were only able to perform up to scores of 99% (there were no scores of 100%), whilst the poorest performers, the Pre-to-post group pre-surgery (i.e. HA users), achieved scores greater than 25%, which is significantly above chance performance. The EST also showed good test-retest reliability, and was easily administered.

To further improve the test for future use, it may be worthwhile eliminating a few of the stimuli which were commonly confused. For example, frequent errors for the NH group included confusing the ‘helicopter’ and ‘aeroplane’ stimuli, the ‘tap running’ and ‘river’ stimuli, and selecting the ‘wind’ stimuli as ‘train’. The CI group also confused the ‘tap running’ and ‘river’ stimuli, and mistook the ‘wind’ stimuli to be a ‘train’. If the ‘tap running’ and ‘wind’ stimuli were removed from the EST, this would have eliminated 16 of the 153 errors made by the NH group (11%), and 27 of the 733 errors made by the CI group (4%). The omission of the ‘helicopter’ stimuli would have accounted for a further 10 of the NH errors, however would have had little effect on this group of CI users’ identification scores.

One limitation of this, and other similar studies, is that environmental sound perception in real life situations has many contextual cues; it is unnatural to have only auditory cues available for determining a sound. This could explain why even the NH adults were unable to achieve 100% correct on the EST, and suggests that any score on the EST would probably underestimate performance in real-life contexts. However, the score of this test does provide insight into the relative contribution of different types of auditory information to the identification of environmental sounds, and the differences in this skill between NH individuals, CI users, and HA users.

One other limitation to this study, and an area for future research, is the small number of subjects in the pre-to-post CI participant group. The inclusion of additional subjects may have resulted in the pre-to-post score differences reaching statistical significance. At the time of this study, the CI program involved only received Government funding for approximately 15 CIs per year, of which children were prioritised. Although some funding was available via alternate channels, the number of adult CI recipients was limited, and fluctuated from year to year. This, combined with the time constraints of the study, impacted on the number of subjects in the Pre-to-post participant group. Hence this study could only pilot test the EST as a pre-to-post surgery assessment tool; a future multi-centre study with a larger number of CI recipients would further help to validate the EST.

CONCLUSIONS AND CLINICAL IMPLICATIONS

The purpose of this study was to develop a new, more comprehensive test of environmental sound perception (the EST), and to both compare the performance of experienced CI users to age-equivalent NH listeners, as well as pilot test its clinical use as a pre-to-post assessment tool for environmental sound perception. Results showed that NH participants were significantly better than the Experienced CI recipients at identifying environmental sounds, although the error patterns of both groups indicated the importance of accurate spectral resolution and differentiation for identifying these stimuli. The pilot testing with newly-implanted recipients showed that scores were higher post-surgery with a CI than pre-surgery with HAs, although the lack of subject numbers meant that this difference did not quite reach statistical significance.

This study highlights the importance of temporal cues for the perception of environmental sounds. Subtle differences in spectral characteristics for temporally similar sounds were the most-common cause of confusions, even for NH listeners. The results also suggest that the better performance of the NH participants was largely due to their more accurate spectral resolution and differentiation. It is possible that because a CI is unable to provide the same degree of spectral resolution as the NH auditory system, the importance of temporal cues is even more important for CI recipients.

The findings also highlight that context is an important part of environmental sound recognition. Environmental sound testing with a focus on auditory-alone perception does not allow context to be used by the participant. CI recipients can be counselled on how context cues are important with the identification of acoustic sounds, be it environmental, musical, or speech stimuli, in the natural environment.

Environmental sound perception has been shown in previous studies to be important for quality of life, and contributes to perceived CI benefit for recipients. The EST scores did not correlate with any of the speech perception measures used in this study, implying that environmental sound perception is a separate skill for CI recipients, largely unrelated to speech perception. This implies that it is important for an environmental sound test to be included in any comprehensive assessment of CI benefit.

The EST developed as part of this study was more difficult and more comprehensive than those used in previous research. It was shown to be easily administered, have good test-retest reliability, minimised ceiling and floor effects, and enabled differences between participant groups' abilities to identify environmental sounds to be identified. This suggests the potential of using the EST developed in this study as part of the CI evaluation process, and/or administering it in a pre-post implantation format to evaluate CI benefit. Further research comparing more CI recipients pre-to-post surgery would help to better validate and refine the use of the EST. Environmental sound perception is a task that we undertake every day, and tend to take for granted. However for those with a significant hearing loss, this skill is often not the same 'unconscious' task that it is for a normally hearing person, and can affect a person's quality of life, independence, self-esteem, and safety. Assessing environmental sound perception for a CI recipient would not only provide more information on outcomes, but it could also provide information which may help the recipient to improve their skills in this area.

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FIGURE LEGENDS

Figure 1: Comparison of category means for the Experienced CI group and the NH group
Error Bars = 1SD

Figure 2: Comparison of category means pre- and post- CI surgery, for the Pre-to-post CI group

Table 1: Details of the Experienced CI group

Duration HL: Duration of hearing loss before receiving CI (years)

LFA: Low Frequency Average - the mean of the 250 Hz and 500 Hz thresholds in the non-implanted ear. This was calculated to represent the amount of residual hearing remaining in the non-implanted ear. These frequencies were chosen as CI candidates would be expected to have severe-to-profound hearing losses at 1 kHz and above.

Speech processing strategy: ACE – Advanced Combination Encoder

Speech perception score post-CI: HINT – Hearing in Noise Test; CNC – Consonant Nucleus Consonant word test. Percentage-correct scores.

Parti-cipant	Sex	Age	Duration HL (years)	Ear with CI	LFA (dB HL)	Time with CI (months)	Type of CI & processor	Speech processing strategy	Speech perception score post-CI* (%)			
									HINT quiet	HINT noise**	CNC words	CNC phonemes
1	M	77	77	R	100	22	C124RE Freedom	ACE 1200 Hz	100	83	75	86
2	F	74	42	R	55	23	C124RE Freedom	ACE 1200 Hz	77.35	20.03	40	63.33
3	M	58	38	L	82.5	29	C124R Esprit 3G	ACE 900 Hz	43.1	0	3.5	35.65
4	F	71	22	R	77	10	C124RE Freedom	ACE 900 Hz	98	74	77	89.5
5	F	46	44	L	98.5	25	C124R Esprit 3G	ACE 1200 Hz	46.2	19.6	18	43
6	F	45	45	R	93.5	29	C124R Esprit 3G	ACE 900 Hz	78.4	38.5	29	58.3
7	F	67	67	L	120	11	C124RE Freedom	ACE 1200 Hz	96.2	83.7	63	82.3
8	F	29	15	R	77.5	36	C124R Esprit 3G)	ACE 900 Hz	96	84	80.5	90.5
9	F	68	48	R	105.5	30	C124R Esprit 3G	ACE 900 Hz	100	53	64	86
10	F	41	26	R	66	58	C124R Esprit 3G	ACE 900 Hz	100	#	#	#
Mean		57.6	42.4		87.55	27.3			83.53	50.65	50	70.51

* All speech perception tests were conducted in a CI-only listening condition.

**For the HINT-noise, speech babble noise was used with a signal-to-noise ratio of 10dB.

\# Speech perception data was largely unable to be obtained for participant 10 as the nature of her job meant that she knew the speech materials off by heart.

Table 2: Unaided pure-tone thresholds for the Experienced CI group
'NR' = no response at the limits of the audiometer.
The limit of the audiometer was 110 dB HL for 250 Hz & 8000 Hz, and 120 dB HL for the frequencies 500 Hz - 4000 Hz.

Partici-pant	Un-Implanted Ear (dB HL)						Implanted Ear (dB HL)					
	250 Hz	500 Hz	1000 Hz	2000 Hz	4000 Hz	8000 Hz	250 Hz	500 Hz	1000 Hz	2000 Hz	4000 Hz	8000 Hz
1	90	110	107	125	125	115	94	NR	NR	NR	NR	NR
2	48	62	82	115	125	115	NR	NR	NR	NR	NR	NR
3	66	99	100	115	116	115	NR	NR	NR	NR	NR	NR
4	66	88	86	108	108	115	NR	NR	NR	NR	NR	NR
5	93	104	108	120	125	115	104	115	NR	NR	NR	NR
6	90	97	110	114	125	115	65	65	84	80	114	NR
7	115	125	125	125	125	115	NR	NR	NR	NR	NR	NR
8	65	90	100	115	120	115	110	NR	NR	NR	NR	NR
9	101	110	106	108	125	115	NR	NR	NR	113	NR	NR
10	58	74	84	100	104	115	98	120	NR	114	120	NR

Table 3: Details of the Pre-to-post CI group

Duration HL: Duration of hearing loss before receiving CI (years)

Speech processing strategy: ACE – Advanced Combination Encoder

Speech perception score post-CI: HINT – Hearing in Noise Test; CNC – Consonant Nucleus Consonant word test. Percentage-correct scores.

Parti-cipant	Sex	Age	Dura-tion HL (years)	Time with HA (years)	Type of HA	Ear with CI#	Type of CI & processor	Speech processing strategy	Speech perception score pre-CI (%) (with bilateral HAs)				Speech perception score post-CI (%) (CI-only)			
									HINT quiet	HINT noise*	CNC words	CNC phonemes	HINT quiet	HINT noise*	CNC words	CNC phonemes
1	M	55	15	11	Phonak Sonoforte	R	C124RE Freedom	ACE 900 Hz	69.5	10	34	56	100	98.5	79	91.5
2	M	55	28	23	Phonak Claro	L	C124RE Freedom	ACE 900 Hz	4	9	0	0	95	88.5	86	93.5
3	F	43	41.5	41.5	Phonak Perseo	R	C124RE Freedom	ACE 900 Hz	4	4	1	11.5	39	20.5	9	34
4	M	66	30	12	Phonak Perseo	R	C124RE Freedom	ACE 900 Hz	69.5	10	8	34	83.5	79.5	52	77
Mean		54.75	28.63	87.5					36.75	8.25	10.75	25.38	79.38	71.75	56.5	74

All participants wore bilateral HAs pre-CI.

* For the HINT-noise, speech babble noise was used with a signal-to-noise ratio of 10dB.

Table 4: Sounds included in the initial version of the EST

Arriving Home	Bathroom	Household Appliances	Human	Kitchen	Nature	Office	Traffic	Other
Door bell	Running water	Alarm clock	Baby crying	Doing dishes	Bird(s) chirping	Drawers opening and closing	Aeroplane	Breaking glass
Door opening/ closing	Toilet flushing	Clock ticking	Laughter	Food frying	Cat(s) meowing	Office environment	Car horn	Construction site
Keys jangling	Water Dripping	Hairdryer	Footsteps	*Fridge hum#*	Dog(s) barking	Paper rustling	*Car starting#*	Hand saw
Knock on door		Lawnmower	Many males & females talking at the same time	Whistling kettle	*Ocean#*	Typing on the computer	Fire/ ambulance siren	Classical music
		Telephone ringing	1 male & 1 female talking at the same time		*Rain#*		Helicopter	Modern music
		Vacuum cleaner#	Single female voice		River/ stream babbling		Traffic on a busy road	Restaurant
			Single male voice		Thunder		Train	
			Snoring		Wind blowing			

These 5 items were removed for the final version of the test, subsequent to the pilot testing.

Table 5: Total confusion matrix for the NH group

n=24	STIMULI																																												
RESPONSE	a	b	c	d	e	f	g	h	i	j	k	l	m	n	o	p	q	r	s	t	u	v	w	x	y	z	aa	bb	cc	dd	ee	ff	gg	hh	ii	jj	kk	ll	mm	nn	oo	pp	qq	rr	ss
a) aeroplane	**37**	0	0	7	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	3	4	0	0	0	0	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0
b) car horn	0	**47**	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
c) siren	0	0	**47**	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
d) helicopter	3	0	0	**37**	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	3	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
e) traffic	0	0	0	0	**48**	0	0	0	0	0	0	3	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0	0
f) train	1	0	0	1	0	**47**	0	0	0	0	1	7	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
g) birds	0	0	0	0	0	0	**48**	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
h) cat	0	0	0	0	0	0	0	**48**	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
i) dog	0	0	0	0	0	0	0	0	**48**	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
j) river	0	0	0	0	0	0	0	0	0	**45**	0	0	0	0	0	0	6	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
k) thunder	0	0	0	0	0	0	0	0	0	0	**40**	0	0	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
l) wind	0	0	0	0	0	0	0	0	0	0	4	**37**	0	0	0	0	0	0	0	0	0	0	0	0	6	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
m) doorbell	0	0	0	0	0	0	0	0	0	0	1	0	**45**	0	0	0	0	0	0	0	0	0	2	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
n) door	0	0	0	0	0	0	0	0	0	0	0	0	0	**46**	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0	2	0	0	0	0	0	0	0	0	0
o) keys	0	0	0	0	0	0	0	0	0	0	0	0	0	0	**46**	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
p) knock	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0	**44**	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
q) tap run	0	0	0	0	0	0	0	0	0	3	0	0	0	0	0	0	**39**	0	0	0	5	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
r) toilet	0	0	0	0	0	0	0	0	0	0	1	0	0	0	0	0	3	**47**	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
s) tap drip	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	**48**	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0
t) dishes	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	**47**	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
u) food fry	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	**39**	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	2	0	0	0	0	0	0	0
v) kettle	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	**47**	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
w) alarm	1	0	0	1	0	0	0	0	0	0	0	0	1	0	0	0	0	1	0	0	0	0	**45**	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
x) clock	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0	**48**	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
y) hairdryer	3	1	0	2	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	**32**	0	0	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0
z) mower	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	**41**	0	0	0	0	0	0	0	0	0	1	0	0	0	0	4	0	0	0	0
aa) phone	0	0	0	0	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0	**46**	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
bb) baby	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	**48**	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
cc) laughter	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	**48**	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
dd) footstep	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	**47**	0	0	0	0	0	0	0	1	0	0	0	0	0	0	0
ee) many	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	**45**	1	0	0	0	0	0	0	0	0	0	0	0	0	5
ff) both	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	2	**47**	0	0	0	0	0	0	0	0	0	0	0	0	0
gg) female	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	**47**	0	0	0	0	0	0	0	0	0	0	0	0
hh) male	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	**47**	0	0	0	0	0	0	0	0	0	0	0
ii) snoring	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0	**48**	0	0	0	0	0	0	0	0	0	0
jj) drawers	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	**43**	0	0	0	0	1	0	0	0	0
kk) office	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	**35**	0	0	0	5	0	0	0	0
ll) paper	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	**45**	0	0	0	0	0	0	0
mm) typing	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	2	0	**48**	0	0	0	0	0	0
nn) glass	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0	0	0	1	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	**48**	0	0	0	0	0
oo) construction	3	0	0	0	0	1	0	0	0	0	0	0	1	0	0	4	0	0	0	0	0	0	0	0	2	0	0	0	0	0	0	0	0	0	0	0	2	0	0	0	**37**	0	0	0	1
pp) saw	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	2	0	0	0	0	0	0	0	0	0	0	1	0	0	0	0	0	**48**	0	0	0
qq) classic	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0	0	0	0	**47**	0	0
rr) modem	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	**48**	0
ss) restaurant	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	7	0	0	0	0	0	0	0	**42**
Total Responses	48	48	48	48	48	48	48	48	48	48	48	48	48	48	48	48	48	48	48	48	48	48	48	48	48	48	48	48	48	48	48	48	48	48	48	48	48	48	48	48	48	48	48	48	48
% Correct	**77**	**98**	**98**	**77**	**100**	**98**	**100**	**100**	**100**	**94**	**83**	**77**	**94**	**96**	**96**	**92**	**81**	**98**	**100**	**98**	**81**	**98**	**94**	**100**	**67**	**85**	**96**	**100**	**100**	**98**	**94**	**98**	**98**	**98**	**100**	**90**	**73**	**94**	**100**	**100**	**77**	**100**	**98**	**100**	**88**
																																													Total Mean: 92.92%

Table 6: Category scores for the initial and follow-up tests for the Experienced CI group
Percentage-correct scores are provided: Mean (standard deviation)

Category	Transport	Nature	Arriving Home	Bathroom	Kitchen	Household Appliances	Human	Office	Other	Total
Initial	41.67 (12.42)	55.83 (18.45)	70 (24.44)	60 (31.62)	45 (28.38)	71 (16.63)	67.4 (18.15)	59.75 (19.35)	61.94 (16.41)	**59.18 (22.7)**
Follow-up	40 (15.11)	59.17 (9.17)	67.5 (17.87)	66.67 (22.22)	46.67 (35.83)	60 (17)	75 (14.73)	57.5 (12.08)	55 (15.32)	**58.61 (20.89)**
Combined	41.67 (12.73)	55 (8.29)	68.75 (17.92)	61.67 (22.97)	43.33 (24.78)	65.5 (14.23)	72.5 (15.08)	58.13 (15.04)	59.58 (12.12)	**59.28 (11.48)**

Table 7: Total confusion matrix for the Experienced CI group

n=20	STIMULI																																												
RESPONSE	a	b	c	d	e	f	g	h	i	j	k	l	m	n	o	p	q	r	s	t	u	v	w	x	y	z	aa	bb	cc	dd	ee	ff	gg	hh	ii	jj	kk	ll	mm	nn	oo	pp	qq	rr	ss
a) aeroplane	**1**	1	0	3	6	1	0	0	0	0	5	4	0	0	0	0	0	0	0	0	0	0	0	0	2	5	0	0	0	0	0	0	0	0	2	0	0	0	0	0	2	0	0	0	5
b) car horn	0	**31**	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
c) siren	1	0	**25**	1	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
d) helicopter	1	0	0	**6**	1	1	0	0	0	0	1	3	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0	1	0	0	0	0	0	1	0	0	0	2
e) traffic	7	0	0	4	**18**	3	0	0	0	2	9	7	0	0	0	0	0	1	0	0	0	0	0	0	1	3	0	0	0	0	0	0	0	0	1	0	2	0	0	0	13	0	0	0	7
f) train	2	0	0	10	3	**19**	0	0	0	3	4	6	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0	1	0	1	0	0	0	3	1	3	0	2
g) birds	0	0	0	0	0	0	**40**	0	0	0	0	0	1	0	1	0	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	3	0	0	0	0	0
h) cat	0	0	1	0	0	0	0	**33**	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	5	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
i) dog	0	1	0	0	0	0	0	0	**37**	0	0	0	3	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
j) river	2	0	0	1	1	0	0	0	0	**11**	0	2	0	0	0	0	7	3	0	0	1	0	0	0	6	1	0	0	0	0	0	0	0	0	0	1	1	2	0	0	1	0	1	0	0
k) thunder	0	0	0	0	0	0	0	0	0	0	**6**	1	0	2	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	1	0	0	0	0	0	0	1	0	0
l) wind	5	0	0	0	7	1	0	0	0	2	6	**5**	0	0	0	0	0	0	0	1	1	0	0	0	4	0	0	0	0	0	0	0	0	0	1	3	0	0	0	0	1	0	1	0	2
m) doorbell	0	2	0	0	0	0	0	0	0	0	0	0	**25**	0	0	0	0	0	0	0	0	1	1	0	0	0	3	1	0	0	0	0	0	0	0	0	0	0	0	3	0	0	0	0	0
n) door	1	0	0	0	0	0	0	0	0	0	0	0	0	**28**	0	2	0	0	0	2	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0	0	0	1	0	0	0
o) keys	0	0	0	0	0	0	0	0	0	0	0	0	2	1	**23**	0	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	2	1	12	0	0	0	0	0
p) knock	0	0	0	0	0	0	0	0	0	0	0	0	0	3	0	**34**	0	0	1	0	0	0	0	4	0	0	0	0	2	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
q) tap run	0	0	0	0	0	0	0	0	0	13	0	0	0	0	4	0	**24**	7	0	0	11	3	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	4	0	0	0	0	1	0	0
r) toilet	2	0	0	0	0	0	0	0	0	3	0	0	0	0	0	0	1	**25**	0	1	3	3	0	0	4	0	0	0	0	0	0	0	0	0	0	1	1	0	0	0	1	0	0	0	0
s) tap drip	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	**25**	0	1	0	0	0	0	0	0	0	0	4	0	0	0	0	0	0	0	0	4	1	0	0	0	0	1
t) dishes	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0	0	0	0	**15**	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	6	1	0	2	1	0	0	0	0
u) food fry	0	0	0	0	0	0	0	0	0	2	0	0	0	0	7	0	4	1	0	2	**15**	4	0	0	4	0	0	0	0	0	0	0	0	0	0	0	2	2	0	1	0	0	0	0	0
v) kettle	2	0	0	0	0	1	0	0	0	0	0	0	0	0	3	0	1	0	0	0	5	**22**	4	0	3	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
w) alarm	0	1	0	0	0	0	0	1	0	1	0	0	1	0	1	0	0	0	0	0	1	3	**29**	0	0	0	3	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
x) clock	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	3	0	0	0	0	**32**	0	0	0	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0
y) hairdryer	6	0	0	5	0	1	0	0	0	1	1	1	0	0	0	0	0	0	0	0	0	1	0	0	**11**	1	0	0	0	0	1	0	0	0	3	0	1	0	0	0	0	0	0	0	0
z) mower	0	0	0	3	1	2	0	0	0	1	0	1	0	0	0	0	1	1	0	0	0	0	0	0	1	**25**	0	0	0	0	0	0	0	0	3	1	0	0	0	0	1	0	0	0	0
aa) phone	0	1	0	0	0	0	0	0	0	0	0	0	3	0	0	0	0	0	0	0	0	0	2	0	0	0	**34**	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
bb) baby	1	0	5	0	0	0	0	2	0	0	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0	**32**	2	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0
cc) laughter	0	0	0	0	0	0	0	1	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	**35**	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
dd) footstep	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	6	5	1	0	0	1	0	0	0	0	0	**29**	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
ee) many	0	0	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	**13**	2	0	0	1	0	1	0	0	0	0	0	0	0	5
ff) both	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	18	**23**	1	0	0	0	0	0	0	0	0	0	0	0	0
gg) female	0	0	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	2	2	**38**	0	0	0	0	0	0	0	0	0	0	0	0
hh) male	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	6	13	1	**39**	0	0	0	0	0	0	0	0	0	0	0
ii) snoring	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	**23**	1	0	0	0	0	0	0	0	0	0
jj) drawers	0	0	0	0	0	1	0	0	0	0	0	0	0	3	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	**24**	0	0	1	0	0	0	0	0	0
kk) office	2	0	1	1	0	1	0	0	0	0	0	2	0	1	0	0	0	0	0	7	0	0	0	0	0	0	0	1	0	0	0	0	0	0	0	4	**10**	1	0	0	1	0	1	0	1
ll) paper	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	1	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0	**25**	0	0	0	0	0	0	0
mm) typing	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	2	1	**34**	0	0	0	0	0	0
nn) glass	0	0	1	0	0	0	0	1	0	0	0	0	3	0	1	0	0	1	0	2	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0	**18**	0	0	0	0	0
oo) construction	5	1	1	4	3	7	0	0	0	1	4	5	1	2	0	4	1	1	4	2	0	2	1	3	2	1	0	0	0	7	0	0	0	0	2	0	4	1	0	0	**13**	0	2	0	5
pp) saw	1	1	0	0	0	0	0	1	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0	1	0	0	0	0	0	**38**	0	0	0
qq) classic	0	1	6	0	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0	1	1	0	0	0	0	0	0	0	2	0	0	0	1	0	**28**	0	2
rr) modem	0	0	0	1	0	1	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	**40**	2
ss) restaurant	1	0	0	0	0	1	0	0	0	0	2	2	0	0	0	0	0	0	0	3	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	7	1	0	0	1	0	0	0	**6**
Total Responses	40	40	40	40	40	40	40	40	40	40	40	40	40	40	40	40	40	40	40	40	40	40	40	40	40	40	40	40	40	40	40	40	40	40	40	40	40	40	40	40	40	40	40	40	40
% Correct	**3**	**78**	**63**	**15**	**45**	**48**	**100**	**83**	**93**	**28**	**15**	**13**	**63**	**70**	**58**	**85**	**60**	**63**	**63**	**38**	**38**	**55**	**73**	**80**	**28**	**63**	**85**	**80**	**88**	**73**	**33**	**58**	**95**	**98**	**58**	**60**	**25**	**63**	**85**	**45**	**33**	**95**	**70**	**100**	**15**
																																													Total Mean: 59.28%

Table 8: Total confusion matrix for the Pre-to-post CI group – Pre-Surgery

n=4	STIMULI																																												
RESPONSE	**a**	**b**	**c**	**d**	**e**	**f**	**g**	**h**	**i**	**j**	**k**	**l**	**m**	**n**	**o**	**p**	**q**	**r**	**s**	**t**	**u**	**v**	**w**	**x**	**y**	**z**	**aa**	**bb**	**cc**	**dd**	**ee**	**ff**	**gg**	**hh**	**ii**	**jj**	**kk**	**ll**	**mm**	**nn**	**oo**	**pp**	**qq**	**rr**	**ss**
a) aeroplane	**1**	0	0	1	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	3	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0
b) car horn	0	**7**	0	2	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
c) siren	0	0	**1**	0	0	0	0	0	0	0	0	0	1	0	1	0	0	0	0	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	2	0	1	0	0	0
d) helicopter	0	0	0	**0**	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
e) traffic	1	0	0	2	**6**	2	0	1	0	0	0	1	0	0	1	0	1	0	0	1	0	0	0	0	3	0	0	0	0	0	0	0	0	0	1	1	0	0	0	0	2	0	0	0	0
f) train	0	0	0	0	0	**3**	0	0	0	0	1	0	0	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0	2	1	0	0
g) birds	0	0	0	0	0	0	**2**	3	0	0	0	0	2	0	0	0	2	0	0	0	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
h) cat	0	0	0	0	0	0	0	**0**	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
i) dog	0	0	0	0	0	0	0	0	**8**	0	0	0	1	0	0	0	0	0	2	0	0	0	1	0	0	0	0	0	1	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0
j) river	0	0	0	0	0	1	0	0	0	**2**	0	2	0	0	0	0	1	1	0	0	2	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0	1	0
k) thunder	0	0	0	0	0	1	0	0	0	0	**2**	1	0	0	1	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0	1
l) wind	1	0	0	1	0	0	0	0	0	0	2	**1**	0	0	0	0	0	2	0	0	0	0	0	0	4	0	0	0	0	0	0	0	0	0	2	0	1	0	0	0	1	0	0	0	0
m) doorbell	0	0	0	0	0	0	0	1	0	0	0	0	**1**	0	0	0	0	0	0	0	0	0	1	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0	1	0	0	1	0	0
n) door	0	0	0	0	0	0	0	0	0	1	0	0	0	**5**	0	0	0	0	0	1	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0
o) keys	0	0	0	0	0	0	0	0	0	0	0	0	0	0	**2**	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0
p) knock	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	**7**	0	0	2	0	0	0	0	3	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
q) tap run	0	0	0	0	0	0	0	0	0	2	0	0	0	0	0	0	**2**	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0
r) toilet	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0	**3**	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0	1	0	0	0	0	0	0
s) tap drip	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	**1**	0	0	0	0	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0	1	0	0	0	0	0	0
t) dishes	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0	**0**	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0	0	0	0	0
u) food fry	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0	**2**	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0	1	0	0	0	0	0
v) kettle	0	0	0	0	0	0	2	0	0	0	0	0	0	0	2	0	0	0	0	0	2	**3**	3	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	1	0	0	0	0	0
w) alarm	0	0	0	0	0	0	1	1	0	0	0	0	2	0	0	0	0	0	0	0	0	1	**1**	0	0	0	1	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
x) clock	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0	**3**	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
y) hairdryer	2	0	1	0	0	0	0	0	0	1	1	0	0	0	0	0	0	0	0	0	0	0	0	0	**1**	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
z) mower	1	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	**3**	0	0	0	0	0	0	0	0	1	0	0	0	0	0	1	0	0	0	0
aa) phone	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	**5**	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
bb) baby	0	0	2	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	**6**	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
cc) laughter	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0	**5**	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
dd) footstep	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	2	0	0	0	0	2	0	0	0	0	0	**6**	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
ee) many	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	**5**	1	0	0	0	0	0	0	0	0	0	0	0	0	1
ff) both	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	**5**	0	0	0	0	1	0	0	0	0	0	0	0	0
gg) female	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0	**8**	0	0	0	0	0	0	0	0	0	0	0	0
hh) male	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	**6**	0	0	0	0	1	0	0	0	0	0	0
ii) snoring	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	**2**	0	0	1	0	0	0	0	0	0	0
jj) drawers	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	**3**	0	1	0	1	1	0	0	0	0
kk) office	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	3	0	0	0	0	0	0	0	0	0	0	1	0	0	0	0	0	**2**	0	0	0	0	0	0	0	4
ll) paper	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0	**3**	1	0	0	0	0	0	0
mm) typing	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0	**3**	0	0	0	0	0	0
nn) glass	0	0	0	0	0	0	1	0	0	0	0	0	0	1	0	0	0	1	1	0	1	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	**1**	0	0	0	0	0
oo) construction	2	0	0	2	0	1	0	0	0	1	1	1	0	0	0	1	0	0	0	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	**2**	0	1	0	0
pp) saw	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0	**3**	0	0	0
qq) classic	0	0	3	0	1	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	**4**	1	0
rr) modem	0	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0	**6**	1
ss) restaurant	0	0	0	0	0	0	0	0	0	1	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	2	0	1	0	1	2	1	0	0	0	1	0	0	**1**
Total Responses	8	8	8	8	8	8	8	8	8	8	8	8	8	8	8	8	8	8	8	8	8	8	8	8	8	8	8	8	8	8	8	8	8	8	8	8	8	8	8	8	8	8	8	8	8
% Correct	**13**	**88**	**13**	**0**	**75**	**38**	**25**	**0**	**100**	**25**	**25**	**13**	**13**	**63**	**25**	**88**	**25**	**38**	**13**	**0**	**25**	**38**	**13**	**38**	**13**	**38**	**63**	**75**	**63**	**75**	**63**	**63**	**100**	**75**	**25**	**38**	**25**	**38**	**38**	**13**	**25**	**38**	**50**	**75**	**13**
																																													Total Mean: 39.72%

Table 9: Total confusion matrix for Pre-to-post CI group - Post-surgery

n=4	STIMULI																																												
RESPONSE	a	b	c	d	e	f	g	h	i	j	k	l	m	n	o	p	q	r	s	t	u	v	w	x	y	z	aa	bb	cc	dd	ee	ff	gg	hh	ii	jj	kk	ll	mm	nn	oo	pp	qq	rr	ss
a) aeroplane	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
b) car horn	0	6	0	0	0	0	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
c) siren	0	0	5	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
d) helicopter	0	0	0	2	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
e) traffic	3	0	0	2	4	1	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	1	1	0	0	0	0	0	0	0	0	0	0	1	0	0	0	2	0	0	0	0
f) train	0	0	0	0	1	4	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0	2
g) birds	0	0	0	0	0	0	7	0	0	0	0	0	1	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
h) cat	0	0	0	0	0	0	0	6	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0
i) dog	0	0	0	0	0	0	0	0	7	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
j) river	0	0	0	0	0	0	0	0	0	3	0	1	0	0	0	0	2	0	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
k) thunder	0	0	0	0	0	0	0	0	0	0	2	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
l) wind	1	0	1	0	2	0	0	0	0	0	3	1	0	0	0	0	0	0	0	0	0	0	0	0	2	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0	1
m) doorbell	0	2	0	0	0	0	0	0	0	0	0	0	4	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
n) door	0	0	0	0	0	0	0	0	0	0	0	0	0	6	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0
o) keys	0	0	0	0	0	0	0	0	0	0	0	0	0	0	3	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	3	0	0	0	0	0
p) knock	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	8	0	0	1	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
q) tap run	0	0	0	0	0	0	0	0	0	2	0	0	0	0	3	0	4	2	0	0	0	1	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0	0	0	0	0
r) toilet	0	0	0	0	0	0	0	0	0	2	0	2	0	0	0	0	0	5	0	0	2	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0	0
s) tap drip	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0	0	2	0	0	0	0	0	1	0	0	0	0	0	0	0	0	1	0	0	0	0	0	0
t) dishes	0	0	0	0	0	0	0	0	0	0	0	0	2	0	0	0	0	0	0	2	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	1	0	0	1	0	0	0	0	0
u) food fry	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	6	2	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0	1	0	0	0	0	0
v) kettle	1	0	0	0	0	0	0	0	0	0	1	0	0	0	1	0	1	0	0	0	0	5	1	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0	0	0
w) alarm	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	5	0	0	0	2	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
x) clock	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	3	0	0	0	0	6	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
y) hairdryer	0	0	0	1	0	0	0	0	0	0	0	1	0	0	0	0	1	0	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0	1
z) mower	0	0	0	1	1	0	0	0	0	1	1	0	0	0	0	0	0	0	0	0	0	0	1	0	1	3	0	0	0	0	0	0	0	0	1	0	0	0	0	0	1	0	0	0	0
aa) phone	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	6	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
bb) baby	0	0	1	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	7	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
cc) laughter	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	8	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
dd) footstep	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	3	0	0	0	0	0	0	1	0	0	0	6	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
ee) many	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	6	3	0	0	0	0	1	0	0	0	0	0	0	0	1
ff) both	0	0	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	3	0	0	0	0	1	0	0	0	0	0	0	0	0
gg) female	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	8	0	0	0	0	0	0	0	0	0	0	0	0
hh) male	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	1	0	7	0	0	0	0	0	0	0	0	0	0	0
ii) snoring	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	4	0	0	0	0	0	0	0	0	0	0
jj) drawers	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	5	0	0	0	0	0	0	0	0	0
kk) office	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	2	0	0	0	0	0	0	0	0	0	0	1	0	0	1	0	0	3	0	0	0	1	0	0	0	1
ll) paper	0	0	0	0	0	0	1	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	7	0	0	0	0	0	0	0
mm) typing	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	6	0	0	0	0	0	0
nn) glass	0	0	0	0	0	0	0	0	0	0	0	0	0	2	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	2	0	0	0	0	0
oo) construction	2	0	0	1	0	2	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0	1	0	0	0	0	1	0	0	0	0	0	2	0	0	0	1
pp) saw	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	7	0	0	0
qq) classic	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	5	2	0
rr) modem	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	2	6	0
ss) restaurant	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0	0	1	0	0	0	1	0	0	0	1
Total Responses	8	8	8	8	8	8	8	8	8	8	8	8	8	8	8	8	8	8	8	8	8	8	8	8	8	8	8	8	8	8	8	8	8	8	8	8	8	8	8	8	8	8	8	8	8
% Correct	13	75	63	25	50	50	88	75	88	38	25	13	50	75	38	100	50	63	13	25	75	63	63	75	13	38	75	88	100	75	75	38	100	88	50	63	38	88	75	25	25	88	63	75	13
																																													Total Mean: 57.22%

Table 10: Percentage-correct scores for each participant pre- and post- CI surgery for each category of the EST

Partici-pant	Category (% correct)																		Total	
	Transport		Nature		Arriving Home		Bathroom		Kitchen		Household Appliances		Human		Office		Other			
	Pre	Post	Pre	Post	Pre	Post	Pre	Post	Pre	Post	Pre	Post	Pre	Post	Pre	Post	Pre	Post	Pre	Post
1	33.33	8.33	16.67	33.33	37.5	37.5	0	16.67	16.67	33.33	30	20	68.75	43.75	0	25	8.33	33.33	27.78	28.89
2	16.67	50	33.33	58.33	37.5	75	0	66.67	0	50	30	60	43.75	93.75	37.5	75	41.67	75	30	68.89
3	50	75	50	50	75	100	50	50	50	83.33	40	90	87.5	93.75	75	100	41.67	58.33	58.89	77.78
4	50	50	25	75	37.5	50	50	33.33	16.67	50	30	40	68.75	75	25	62.5	50	25	42.22	53.33
Mean	**37.5**	**45.83**	**31.25**	**54.17**	**46.88**	**65.63**	**25**	**41.67**	**20.83**	**54.17**	**32.5**	**52.5**	**67.19**	**76.56**	**34.38**	**65.63**	**35.42**	**47.92**	**39.72**	**57.22**
SD	**15.96**	**27.64**	**14.23**	**17.35**	**18.75**	**27.72**	**28.87**	**21.52**	**20.97**	**20.97**	**5.0**	**29.86**	**17.95**	**23.59**	**31.25**	**31.25**	**18.48**	**22.95**	**14.27**	**21.42**